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Ashkenazi et al.

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(45) **Date of Patent: Nov. 12, 2024**

(54) **OPTICAL SEE THROUGH (OST) NEAR EYE DISPLAY (NED) SYSTEM INTEGRATING OPHTHALMIC CORRECTION**

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G02B 27/00 (2006.01)

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CPC ***G02B 27/0172*** (2013.01); ***G02B 17/08*** (2013.01); ***G02B 27/0025*** (2013.01);
(Continued)

(58) **Field of Classification Search**
CPC G02B 17/08; G02B 27/0025; G02B 27/0093; G02B 27/0172; G02B 27/0176;
(Continued)

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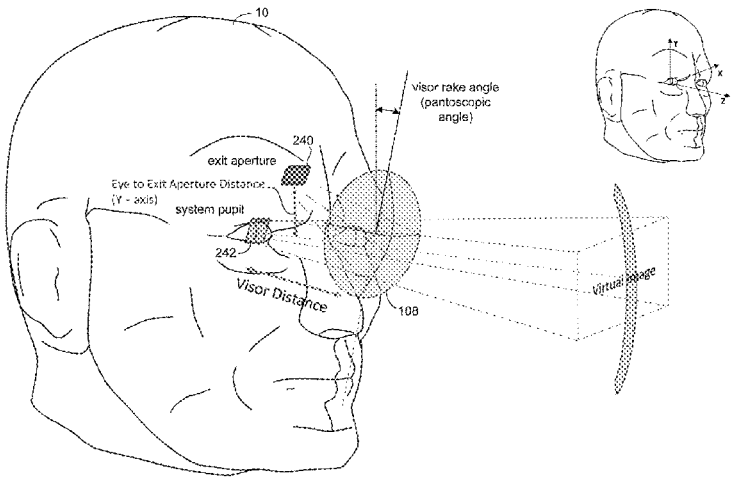
(57) **ABSTRACT**

An optical see-through (OST) near-eye display (NED) system, integrating ophthalmic correction for an eye of a user, includes a partially transmissive partially reflective lens, including an inner surface having an inner surface radius of curvature exhibiting a first optical power. An outer surface has an outer surface radius of curvature exhibiting a second optical power. The lens is faces the eye to transmit incoming light of an outward scene to the eye. An electro-optical unit optically couples with the lens, and includes a light display projecting a light beam image onto the inner surface, to reflect the light beam image toward the eye. The electro-optical unit is located at a user's glabellar region. The first optical power provides ophthalmic correction with respect to the reflected light beam image. The second optical power is configured to provide ophthalmic correction with respect to transmitted incoming light from the outward scene.

17 Claims, 12 Drawing Sheets



(52) **U.S. Cl.**
CPC ***G02B 27/0093*** (2013.01); *G02B 2027/014* (2013.01); *G02B 2027/0178* (2013.01); *G02B 2027/0187* (2013.01)

(58) **Field of Classification Search**
CPC G02B 2027/0138; G02B 2027/014; G02B 2027/0178; G02B 2027/0187; G02B 27/005
See application file for complete search history.

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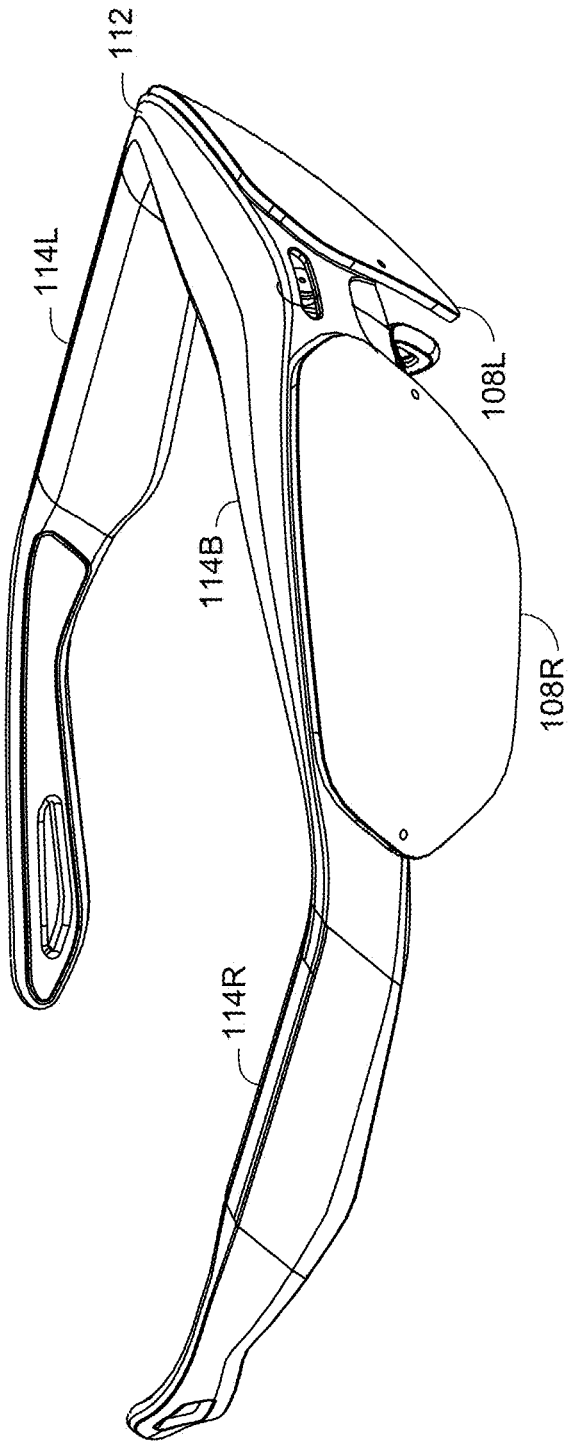

FIG. 1

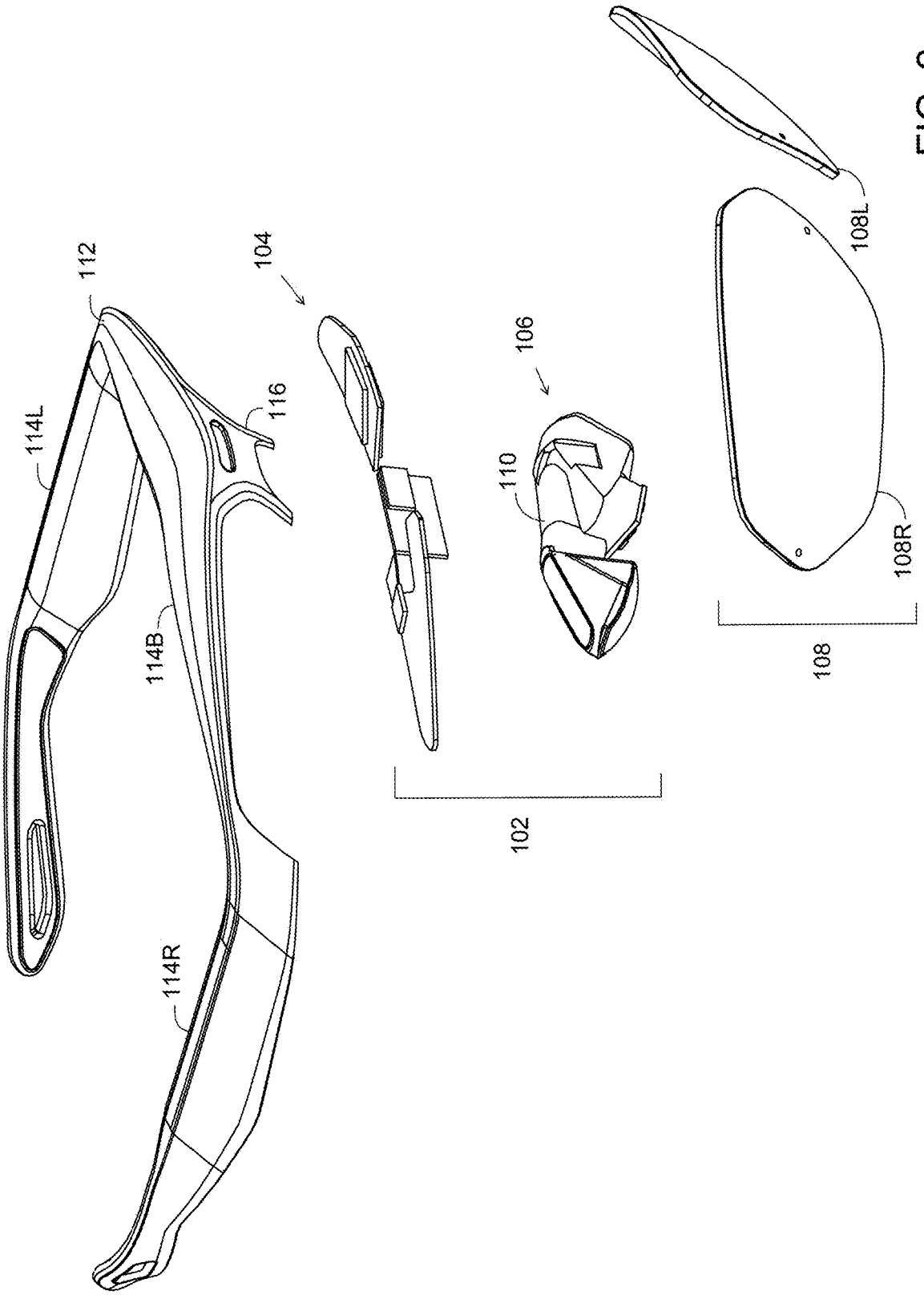

FIG. 2

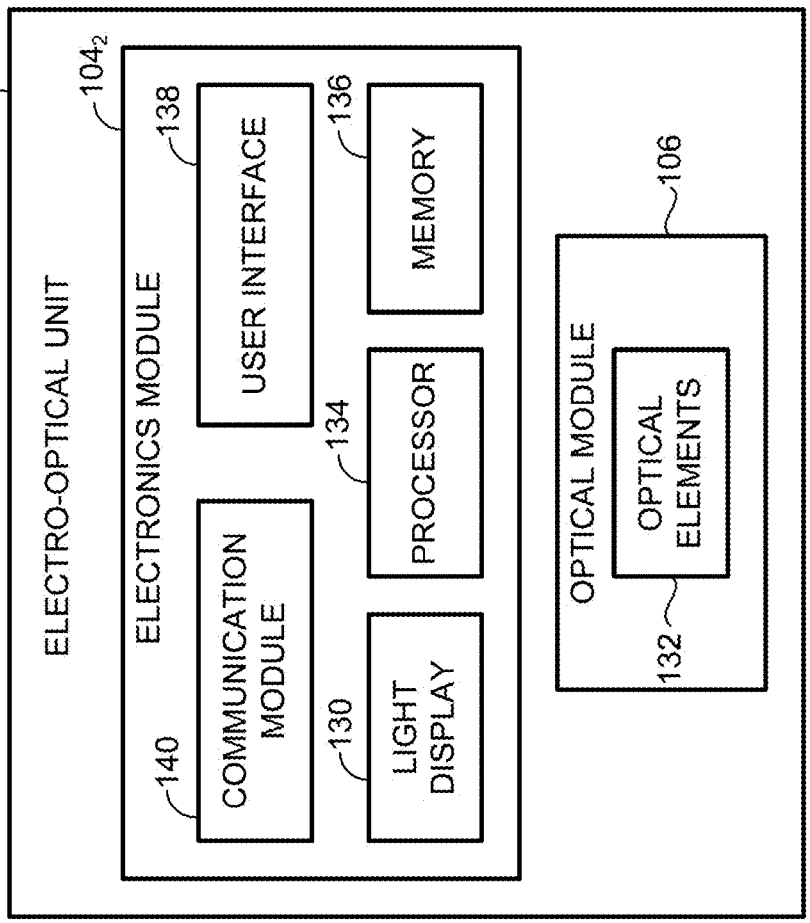
102₂
ELECTRO-OPTICAL UNIT
104₂
ELECTRONICS MODULE
138
USER INTERFACE
136
MEMORY
140
COMMUNICATION MODULE
130
LIGHT DISPLAY
134
PROCESSOR
106
OPTICAL MODULE
OPTICAL ELEMENTS
132

FIG. 3B

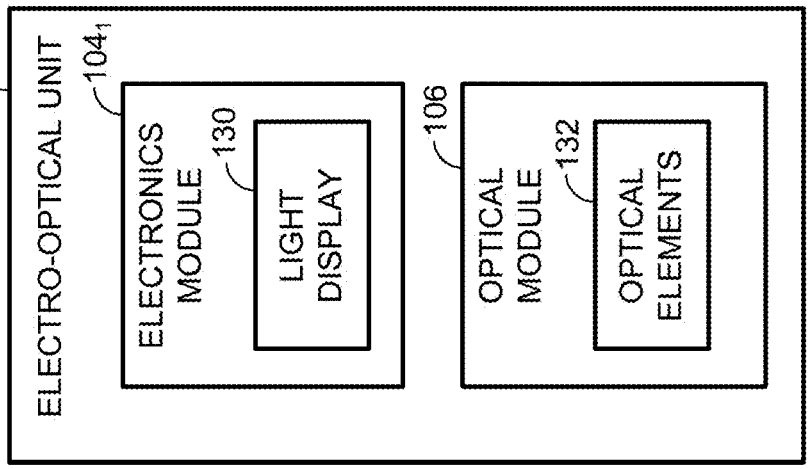
102₁
ELECTRO-OPTICAL UNIT
104₁
ELECTRONICS MODULE
130
LIGHT DISPLAY
106
OPTICAL MODULE
132
OPTICAL ELEMENTS

FIG. 3A

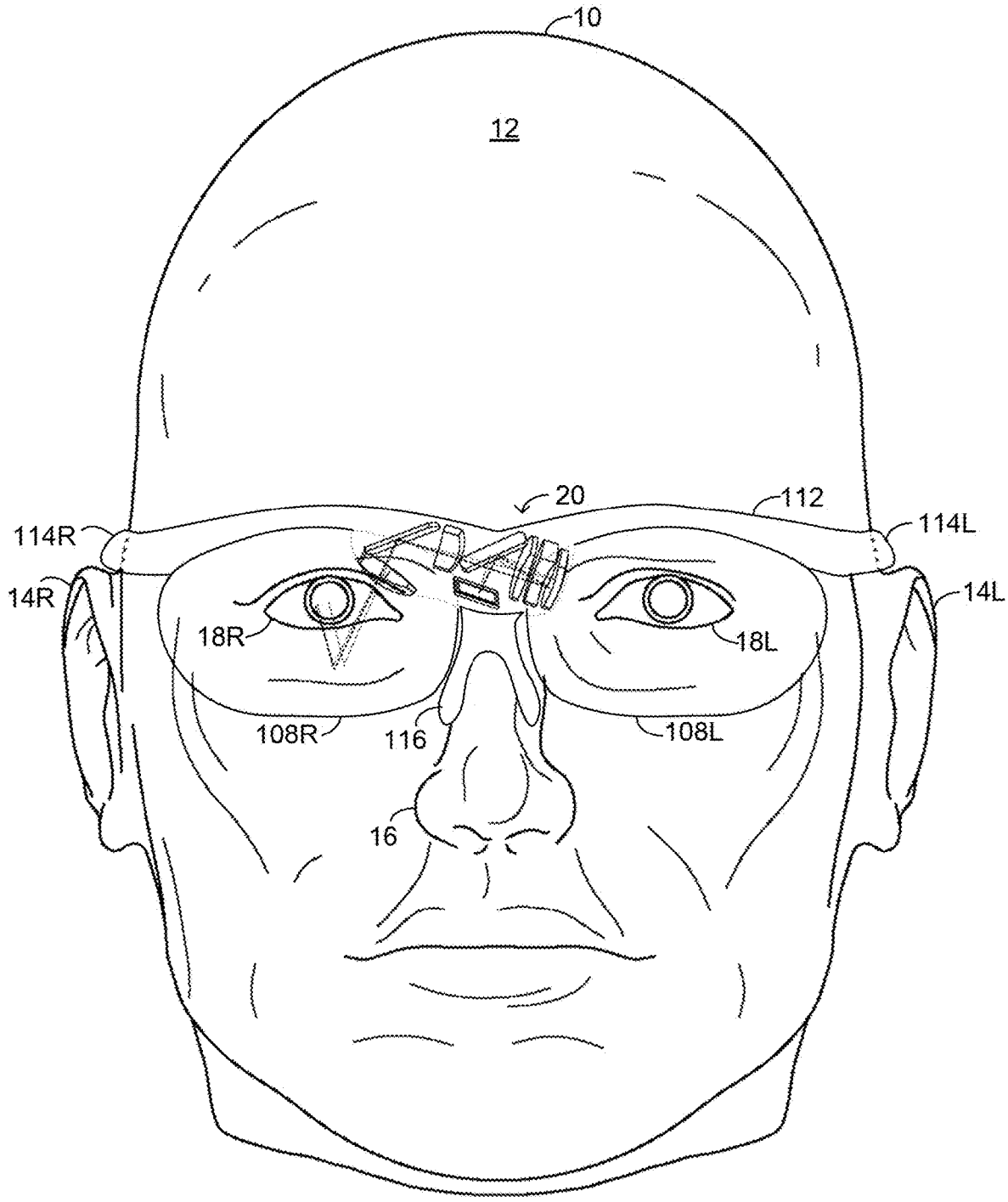

FIG. 4

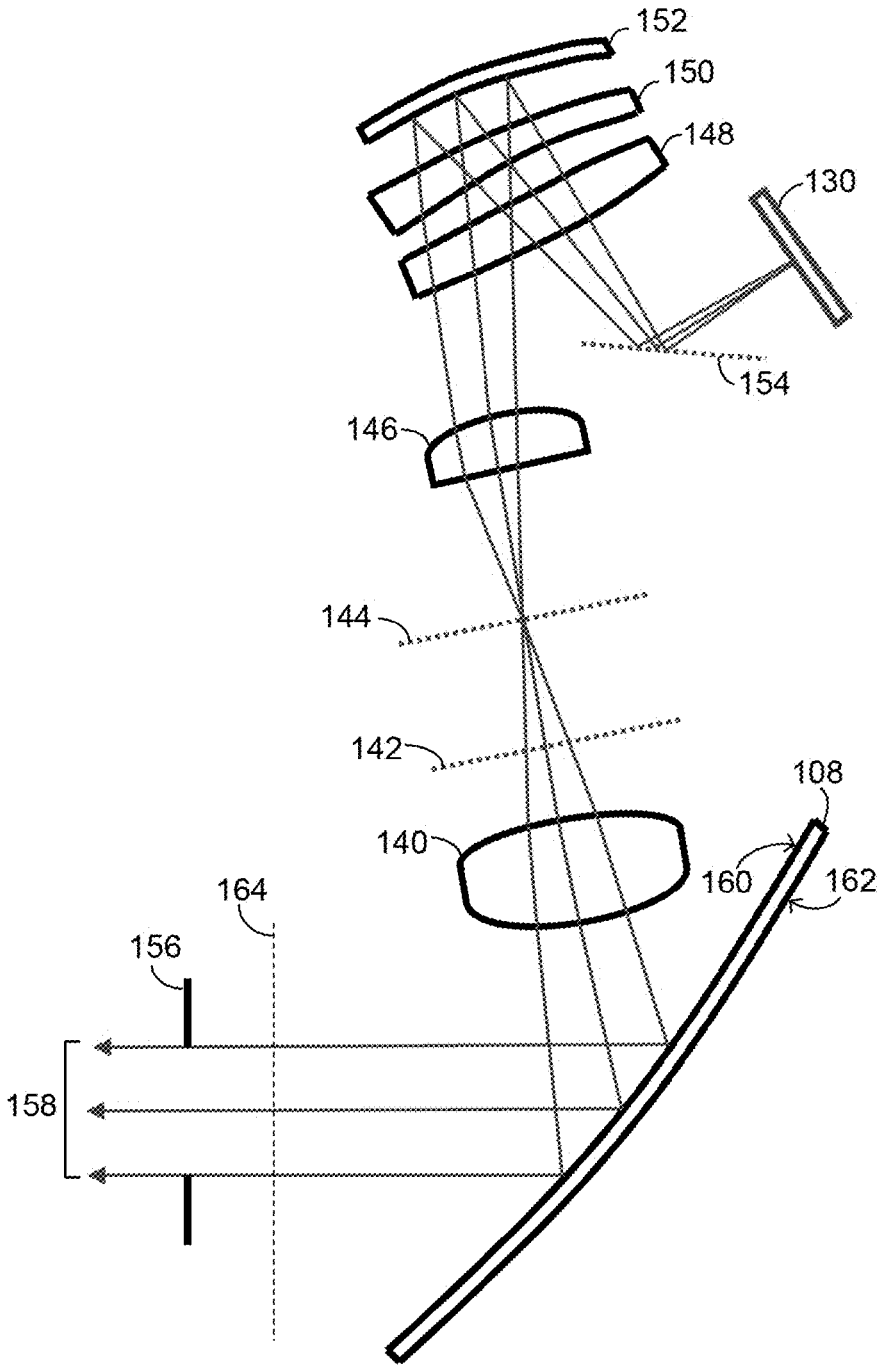

FIG. 5

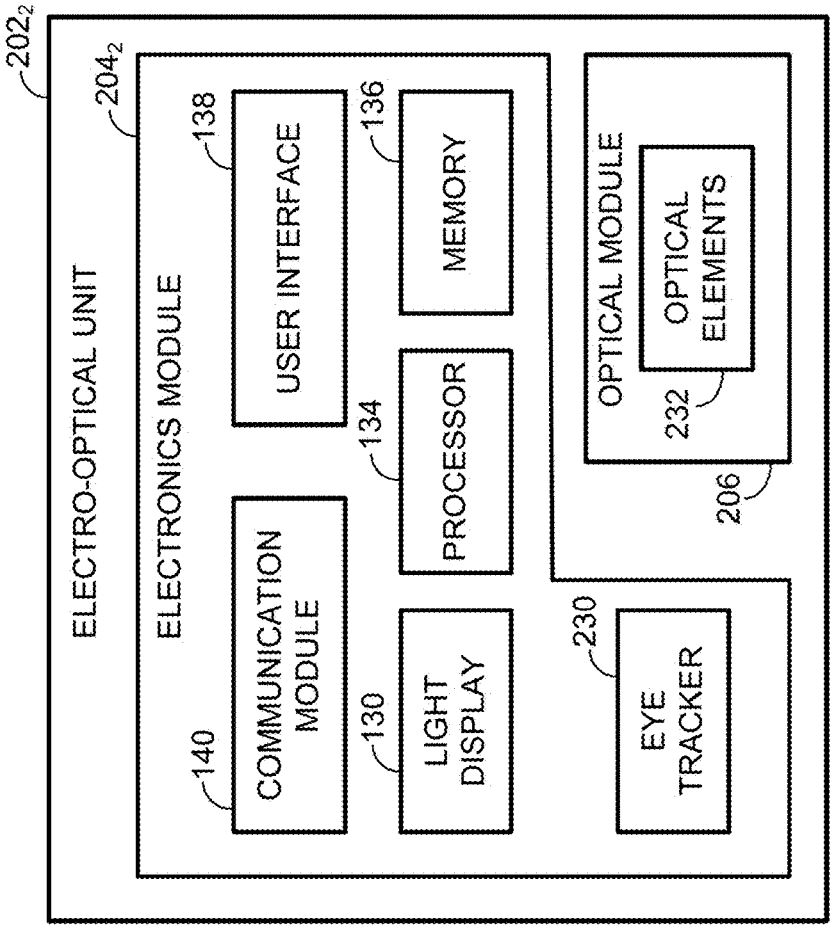
202_2
ELECTRO-OPTICAL UNIT
204_2
ELECTRONICS MODULE
138
USER INTERFACE
136
MEMORY
134
PROCESSOR
140
COMMUNICATION MODULE
130
LIGHT DISPLAY
230
EYE TRACKER
OPTICAL MODULE
232
OPTICAL ELEMENTS
206

FIG. 6B

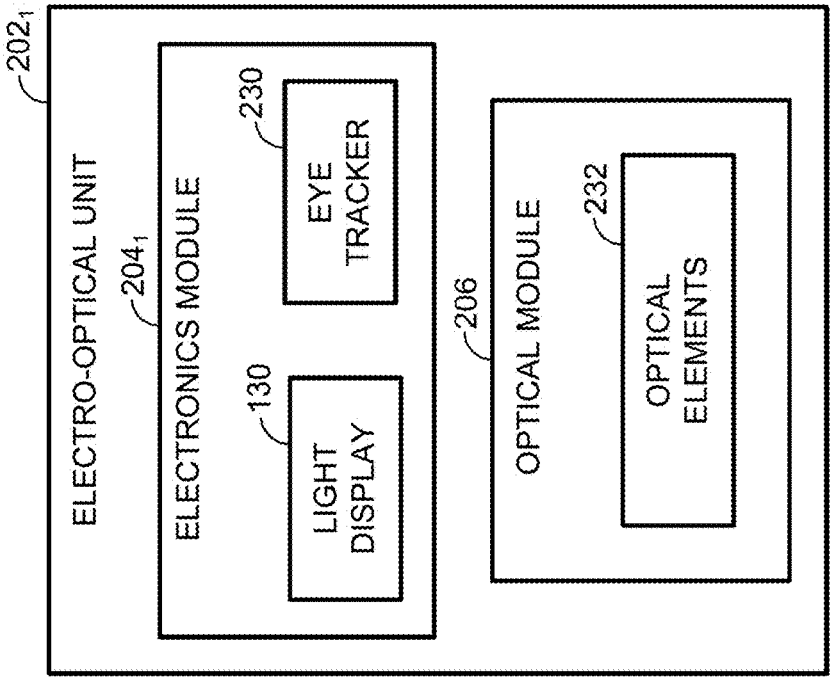
202_1
ELECTRO-OPTICAL UNIT
204_1
ELECTRONICS MODULE
230
EYE TRACKER
130
LIGHT DISPLAY
206
OPTICAL MODULE
232
OPTICAL ELEMENTS

FIG. 6A

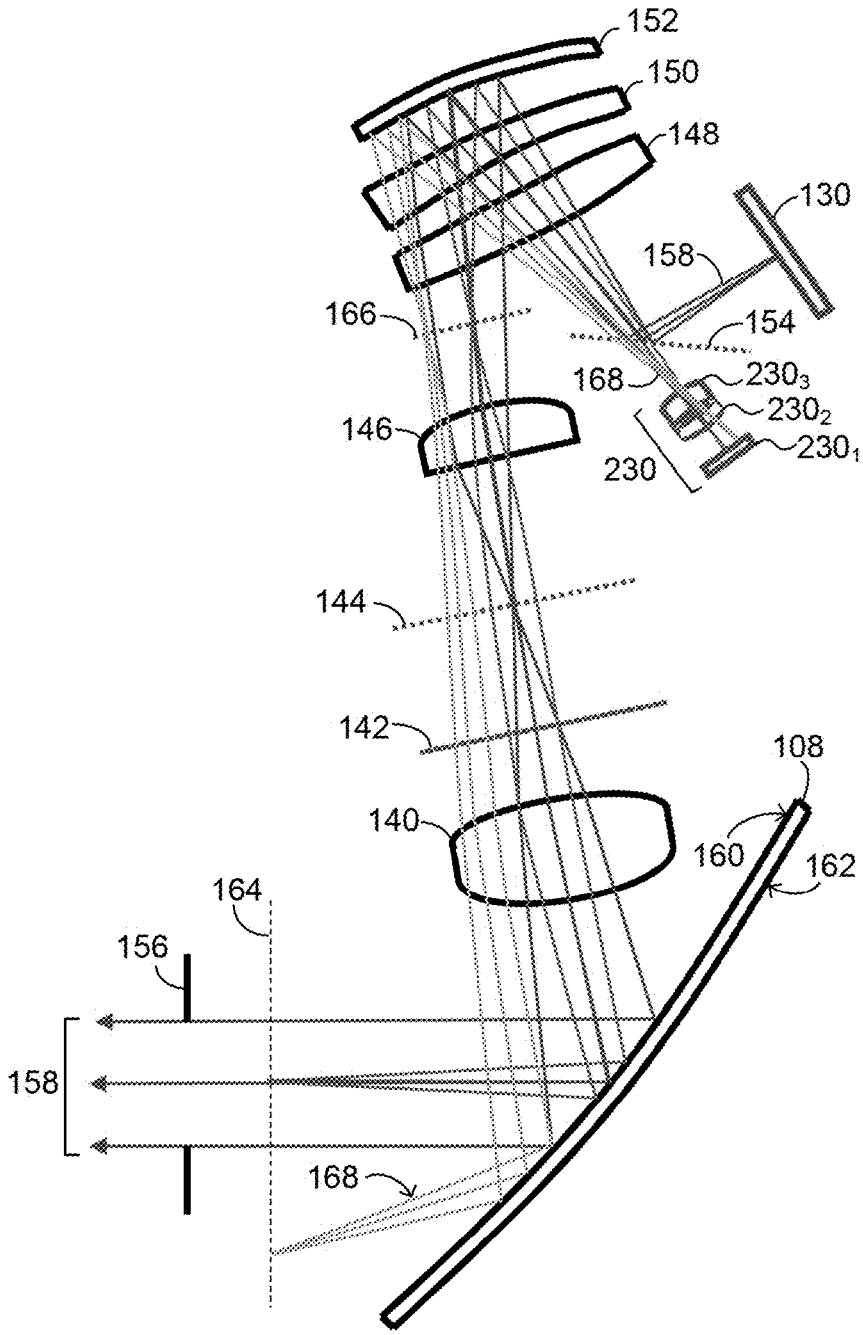
152
150
148
130
158
166
154
168
230_3
230_2
146
230_1
230
144
142
108
140
160
162
164
156
158
168

FIG. 7

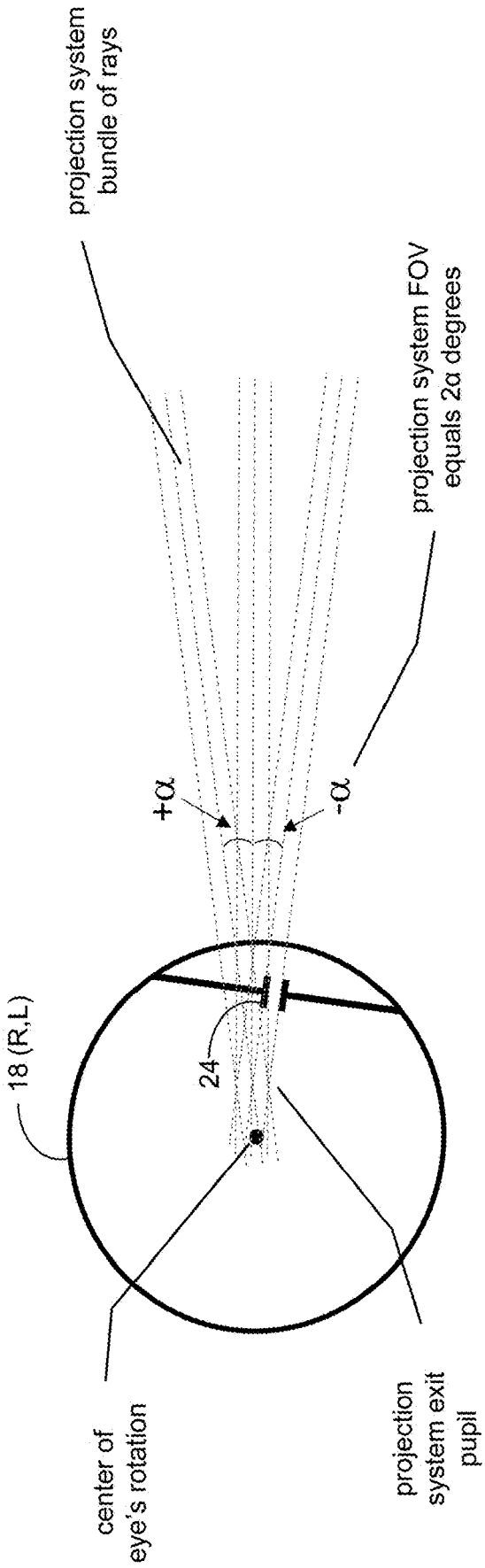
projection system bundle of rays
projection system FOV equals 2α degrees
+α
-α
18 (R,L)
24
center of eye's rotation
projection system exit pupil

FIG. 8A

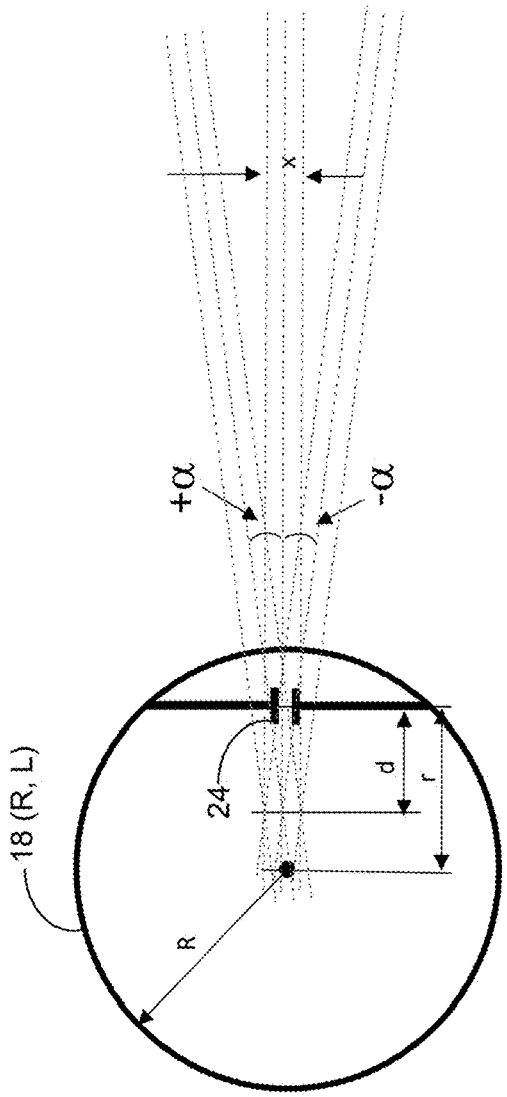
x
+α
-α
18 (R, L)
24
d
r
R

FIG. 8B

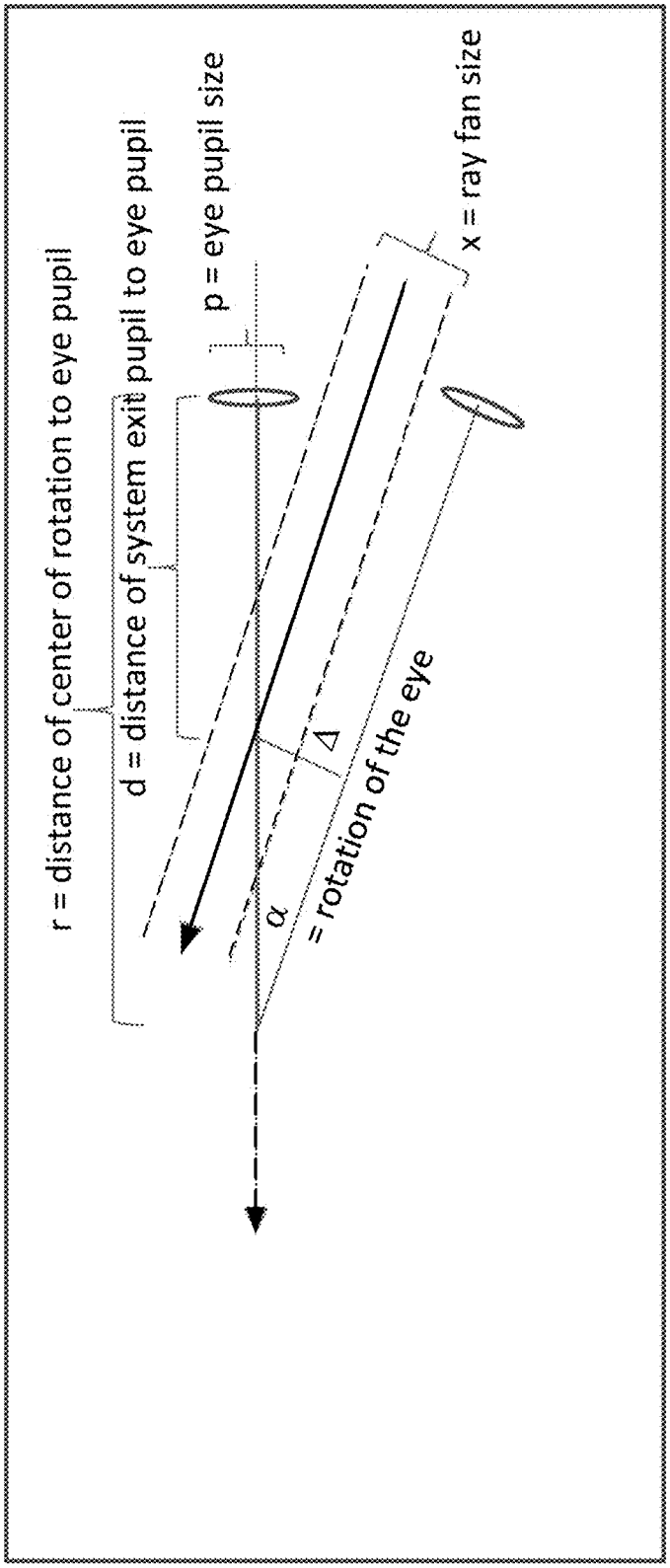
r = distance of center of rotation to eye pupil
d = distance of system exit pupil to eye pupil
p = eye pupil size
x = ray fan size
α
= rotation of the eye

FIG. 8C

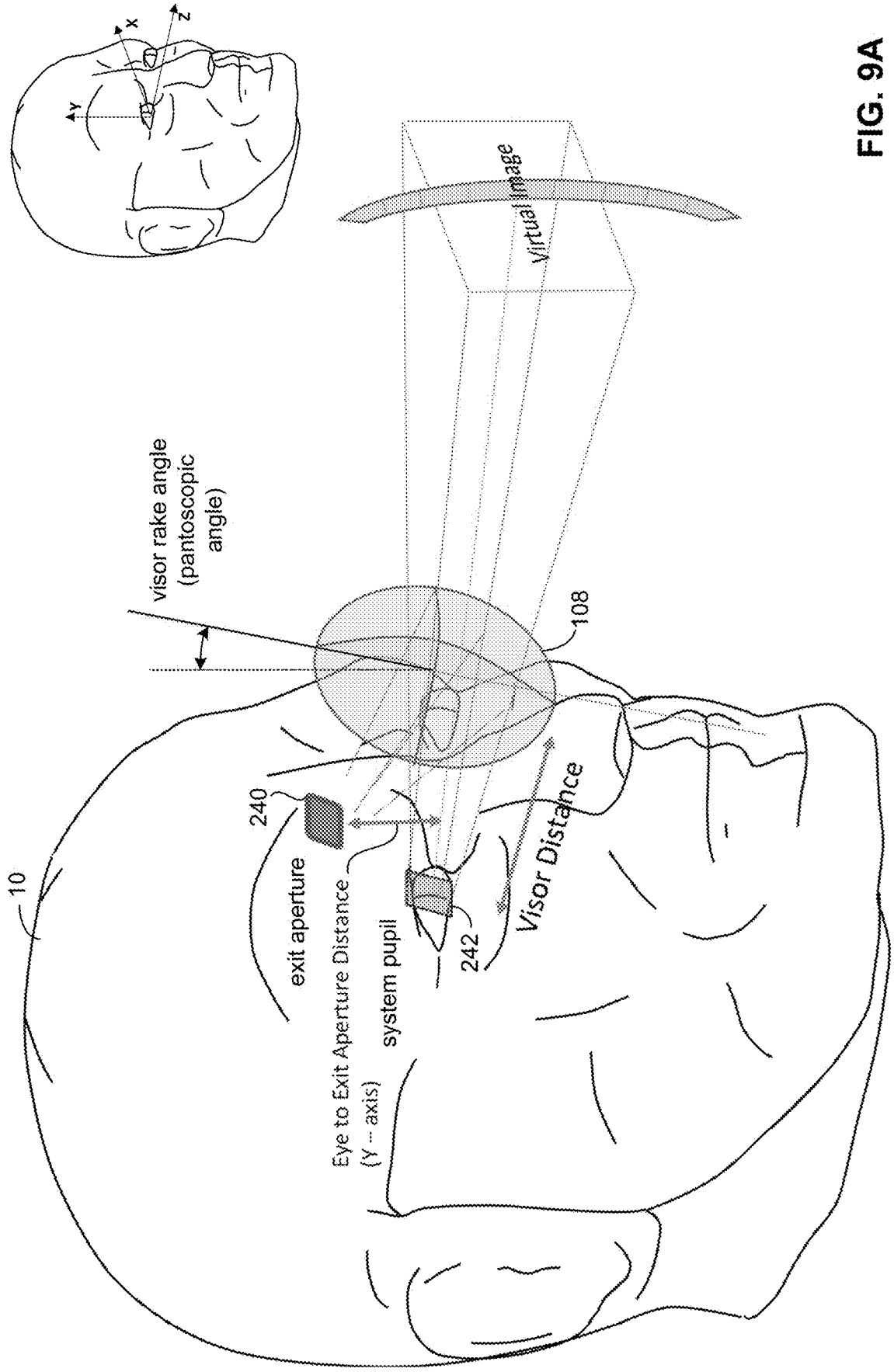
x
z
y
Virtual Image
visor rake angle
(pantoscopic
angle)
108
240
exit aperture
Eye to Exit Aperture Distance
(Y -- axis)
system pupil
242
Visor Distance
10

FIG. 9A

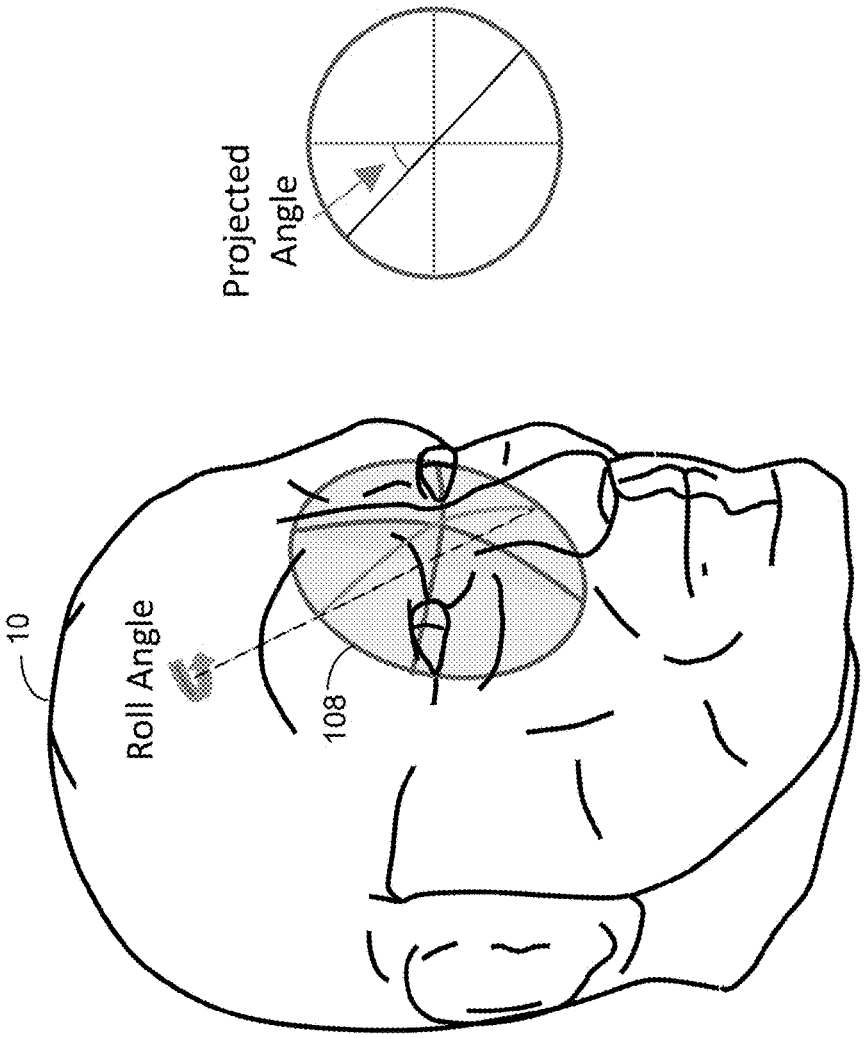
Projected Angle
10
Roll Angle
108
Pantoscopic angle
108
18
Wrap angle
108
112

FIG. 9B

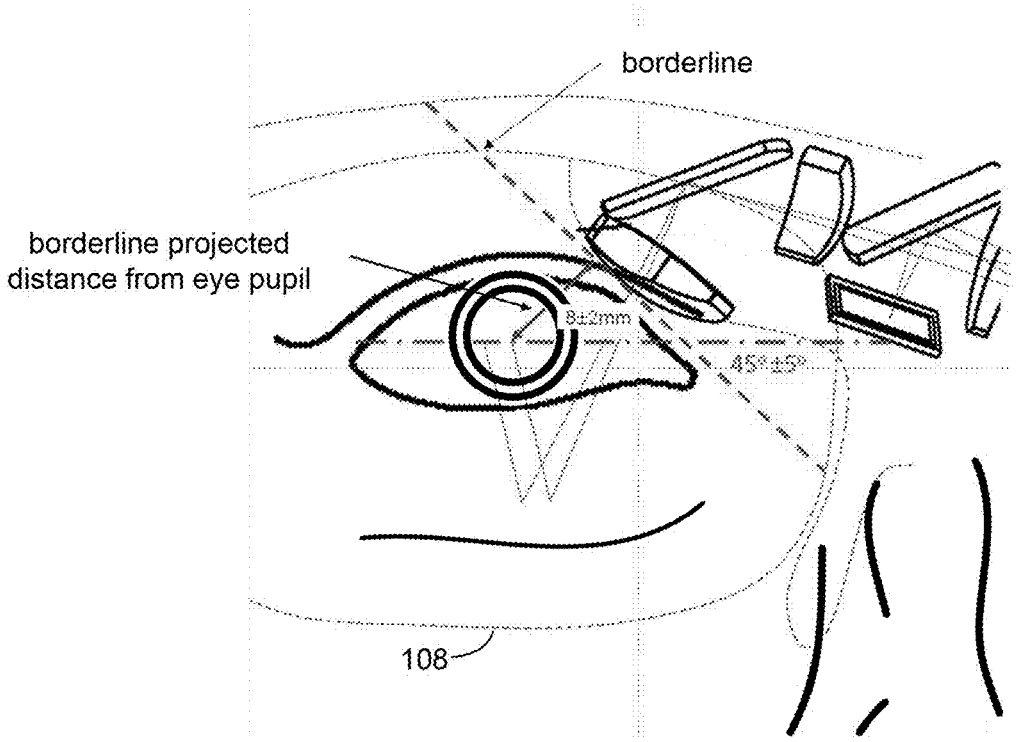

FIG. 10A

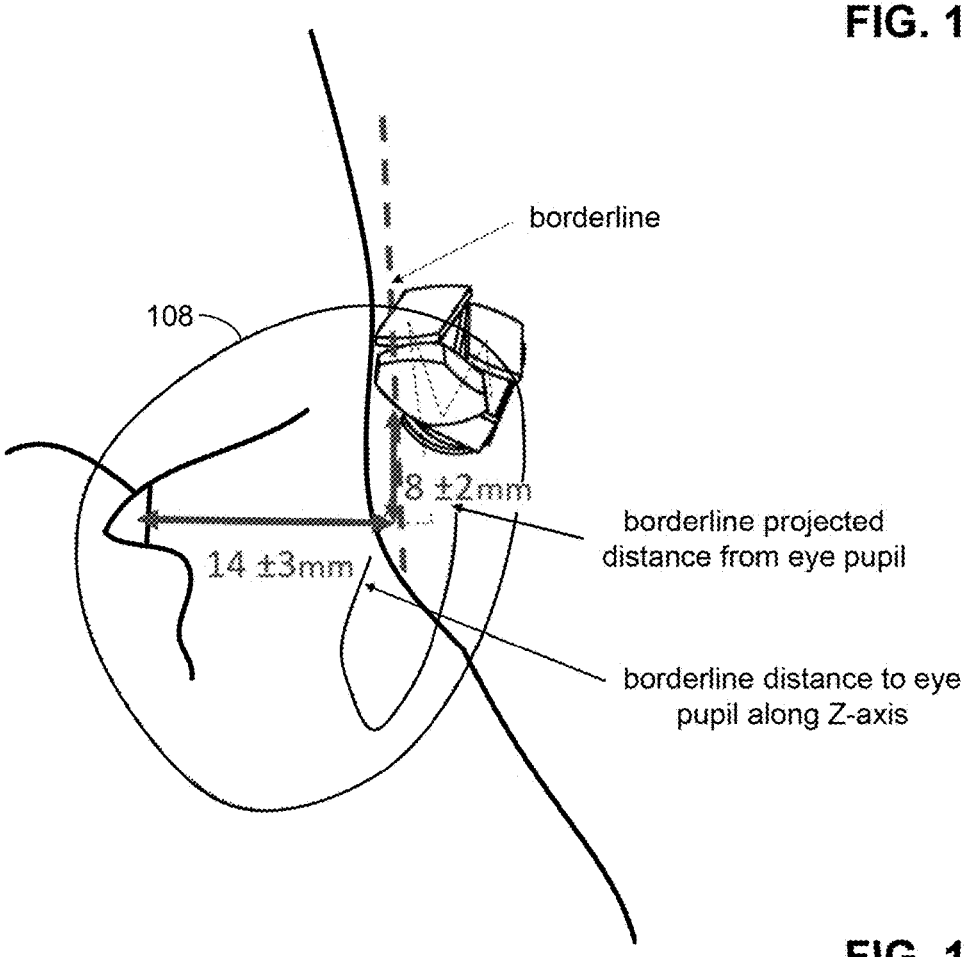

FIG. 10B

OPTICAL SEE THROUGH (OST) NEAR EYE DISPLAY (NED) SYSTEM INTEGRATING OPHTHALMIC CORRECTION

This application is a National Stage of PCT/IL2020/050599, filed May 28, 2020, which claims benefit of Application No. 266969, filed May 28, 2019 in Israel, which applications are incorporated herein by reference. To the extent appropriate, a claim of priority is made to each of the above-disclosed applications.

FIELD OF THE DISCLOSED TECHNIQUE

The disclosed technique relates to optical systems in general, and to wearable optical display systems, in particular.

BACKGROUND OF THE DISCLOSED TECHNIQUE

U.S. Patent Application Publication No.: US 2015/0168730 A1 to Ashkenazi et al. is directed at a user wearable optical display system that provides information in the form of projected light to a user who wears the system without obstructing the user's field of regard (FOR). The user wearable optical display system includes a user attachment section, a partially transmissive partially reflective lens, and an electro-optical unit. The user attachment section is for detachably mounting the user wearable optical display system to a head of a user. The partially transmissive partially reflective lens, which is coupled with the user attachment section, is configured to be facing at least one eye of the user. The electro-optical unit is coupled with at least one of the user attachment section and the partially transmissive partially reflective lens. The electro-optical unit includes a processor, and a light projection unit. The processor is coupled with the light projection unit. The light projection unit is configured to transmit light beams onto the partially transmissive partially reflective lens. The electro-optical unit is configured to be positioned with respect to the user attachment section such that when the user wearable optical display system is mounted on the user, the electro-optical unit is located at the glabellar region of the user.

SUMMARY OF THE PRESENT DISCLOSED TECHNIQUE

It is an object of the disclosed technique to provide a novel optical see-through (OST) near-eye display (NED) system, integrating ophthalmic (vision) correction for an eye of a user. The OST NED system includes a partially transmissive partially reflective lens, and an electro-optical unit. The partially transmissive partially reflective lens includes an inner surface characterized by an inner surface radius of curvature exhibiting a first optical power, and an outer surface characterized by an outer surface radius of curvature exhibiting a second optical power. The partially transmissive partially reflective lens is configured to be facing the eye of the user, and to at least partially transmit incoming light of an outward scene to the eye. The electro-optical unit is configured to be optically coupled with the partially transmissive partially reflective lens. The electro-optical unit includes a light display configured to project a light beam image onto the inner surface, so to enable reflection of the light beam image toward the eye. The electro-optical unit is configured to be located at a glabellar region of the user. The first optical power is configured to provide ophthalmic correction with respect to reflected light beam image for viewing by the eye, wherein the second optical power is configured to provide ophthalmic correction with respect to transmitted incoming light from the outward scene for viewing by the eye.

In accordance with another embodiment of the disclosed technique there is provided an optical configuration for an optical see-through (OST) eye-tracking system. The optical configuration includes a partially transmissive partially reflective lens, and an electro-optical unit (sub-system). The partially transmissive partially reflective lens is configured to be facing an eye of a user. The electro-optical unit (sub-system) includes an image sensor, configured to acquire at least one image of an eyeball feature of the eye with reflected light from the eye; a first lens; a second lens; a third lens; a fourth lens; a curved mirror; an optical combiner; and a fifth lens. The optical configuration enables the reflected light to travel along an optical path at least partially reflecting from the partially transmissive partially reflective lens, then refracting through the first lens, the second lens, the third lens, and the fourth lens, then reflecting from the curved mirror and refracting again in reverse order through the fourth lens and then through the third lens, then at least partially passing through the optical combiner, refracting through the fifth lens, and impinging on the image sensor.

BRIEF DESCRIPTION OF THE DRAWINGS

The disclosed technique will be understood and appreciated more fully from the following detailed description taken in conjunction with the drawings in which:

FIG. **1** is a schematic illustration of an optical see-through (OST) near-eye display (NED) system, integrating ophthalmic correction for an eye of a user, constructed and operative in accordance an embodiment of the disclosed technique;

FIG. **2** is a schematic illustration of the OST NED system of FIG. **1** in an exploded view;

FIG. **3**A is a schematic block diagram of a basic configuration of the electro-optical unit of OST NED system, constructed and operative in accordance with the embodiment of the disclosed technique;

FIG. **3**B is a schematic block diagram of an accessorized configuration of the electro-optical unit of OST NED system, constructed and operative in accordance with the embodiment of the disclosed technique;

FIG. **4** is a schematic illustration showing OST NED system of FIGS. **1** and **2** in a mounted configuration on a user;

FIG. **5** is a schematic diagram of a light path through an optical module of electro-optical unit of OST, constructed and operative in accordance with the embodiment of the disclosed technique;

FIG. **6**A is a schematic block diagram of a basic configuration of an electro-optical unit of OST eye-tracking system, constructed and operative in accordance with another embodiment of the disclosed technique;

FIG. **6**B is a schematic block diagram of an accessorized configuration of an electro-optical unit of OST eye-tracking system, constructed and operative in accordance with the embodiment of the disclosed technique;

FIG. **7** is a schematic diagram of a light path through an optical module of electro-optical unit of OST eye-tracking system, constructed and operative in accordance with the embodiment of the disclosed technique;

FIG. **8**A is a schematic illustration showing the principles of the non-pupil forming optical design upon which OST

NED system **100** and OST NED eye-tracking system **200** are based, in accordance with the embodiments of the disclosed technique;

FIG. **8**B is a schematic illustration showing the a simplified geometric representation of a human eye, looking at a projected image focused at a far distance, and generated by a non-forming exit pupil display system design upon which OST NED system **100** and OST NED eye-tracking system **200** are based, in accordance with the embodiments of the disclosed technique;

FIG. **8**C is a schematic illustration showing determination of the distance, d, of the system exit pupil to the eye pupil, according to the disclosed technique;

FIG. **9**A is a schematic illustration showing optical design features of the systems of the disclosed technique with respect to an eye motion box in relation to an exit aperture;

FIG. **9**B is a schematic illustration showing a pantoscopic angle, a wrap angle, and a roll angle, according to the principles of the disclosed technique;

FIG. **10**A is a schematic illustration showing a front-facing detailed partial view of characteristic design constraints of the systems of the disclosed technique; and

FIG. **10**B is a schematic illustration showing a detailed side partial view of characteristic design constraints of the systems of the disclosed technique.

DETAILED DESCRIPTION OF THE EMBODIMENTS

The disclosed technique overcomes the disadvantages of the prior art by providing a free-space optical see-through (OST) near-eye display (NED) system integrating ophthalmic correction for an eye of a user of the system. The OST NED system includes a partially transmissive partially reflective lens, and an electro-optical unit. The partially transmissive partially reflective lens includes an inner surface, and an outer surface. The inner surface is characterized by an inner surface radius of curvature exhibiting a first optical power, and an outer surface characterized by an outer surface radius of curvature exhibiting a second optical power. The partially transmissive partially reflective lens is configured to be facing an eye of the user, and further configured to at least partially transmit incoming light of an outward scene to that eye. The electro-optical unit is configured to be optically coupled with the partially transmissive partially reflective lens. The electro-optical unit includes a light display configured to project a light beam image onto the inner surface, so as to enable reflection of the light beam image toward the eye. The electro-optical unit is configured to be located at a glabellar region of the user. The first optical power of the inner surface is configured to provide ophthalmic correction with respect to the reflected light beam image for viewing by the eye, and the second optical power is configured to provide ophthalmic correction with respect to transmitted incoming light from the outward scene for viewing by the eye.

According to another aspect of the disclosed technique, there is thus provided a free-space optical configuration for an OST eye-tracking system that includes a partially transmissive partially reflective lens, and an electro-optical sub-system. The electro-optical sub-system includes an images sensor, a first lens, a second lens, a third lens, a fourth lens, a curved mirror, an optical combiner, and a fifth lens. The partially transmissive partially reflective lens is configured to be facing an eye of a user. The image sensor is configured to acquire at least one image of an eyeball feature of the eye with reflective light from the eye. The optical configuration enables reflected the reflected light to travel along an optical path at least partially reflecting from the partially transmissive partially reflective lens, then refracting through the first lens, the second lens, the third lens, the fourth lens, then reflecting from the curved mirror and refracting again in reverse order through the fourth lens and then through the third lens, then at least partially passing through the optical combiner, refracting through the fifth lens, and impinging on the image sensor.

Reference is now made to FIGS. **1** and **2**. FIG. **1** is a schematic illustration of an optical see-through (OST) near-eye display (NED) system, integrating ophthalmic correction for an eye of a user, generally referenced **100**, constructed and operative in accordance an embodiment of the disclosed technique. FIG. **2** is a schematic illustration of the OST NED system of FIG. **1** in an exploded view. OST NED system **100** includes an electro-optical unit **102** and at least one partially transmissive partially reflective lens **108**. Electro-optical unit **102** includes an electronics module **104** (FIG. **2**), and an optical module **106**. Optical module **106** is configured to be at least partially housed in an optical housing **110** (FIG. **2**). Electro-optical unit **102** is configured to be mechanically and optically coupled such to have fixed position and orientation with respect to at least one partially transmissive partially reflective lens **104** (i.e., and vice-versa).

FIGS. **1** and **2** show a user attachment section **112** that enables the detachable coupling of OST NED system **100** to a user (i.e., to be worn by a user). User attachment section **112** is typically embodied in the form of a frame (e.g., resembling eye glasses) and includes two temples **114**R and **114**L (interchangeably "stem portions"), a bridge **114**B ("bridge portion") that couples between stem portions **114**L and **114**R, and a nosepiece **116**. The terms "user attachment section" and "frame" are herein interchangeable and refer to a device, object or group of objects configured and operative to couple with a wearer of OST NED system **100**. FIGS. **1** and **2** illustrate two partially transmissive partially reflective lenses, namely, a partially transmissive partially reflective lens **108**R (denoted interchangeably herein simply "lens", "combiner", "optical combiner"), and partially transmissive partially reflective lens **108**L, each configured to be facing a different eye of a user wearing OST NED system **100**.

Reference is now further made to FIGS. **3**A, **3**B, **4**, and **5**. FIG. **3**A is a schematic block diagram of a basic configuration of the electro-optical unit of OST NED system, constructed and operative in accordance with the embodiment of the disclosed technique. FIG. **3**B is a schematic block diagram of an accessorized configuration of the electro-optical unit of OST NED system, constructed and operative in accordance with the embodiment of the disclosed technique. FIG. **4** is a schematic illustration showing OST NED system of FIGS. **1** and **2** in a mounted configuration on a user. FIG. **5** is a schematic diagram of a light path through an optical module of electro-optical unit of OST, constructed and operative in accordance with the embodiment of the disclosed technique. FIG. **3**A illustrates a basic configuration of electro-optical unit **102** of OST NED system **100**, denoted by $\mathbf{102}_1$. Electro-optical unit $\mathbf{102}_1$ includes an electronics module $\mathbf{104}_1$, and optical module **106**. Electronics module $\mathbf{104}_1$ includes a light display **130**. Optical module **106** includes optical elements, collectively referenced **132** that are particularized in greater detail in FIG. **5**. Light display **130** of electronics module $\mathbf{104}_1$ along with optical elements **132** of optical module **106** form a light projector that is configured and operative to produce, irradiate, and project a light beam image (not shown) onto at least one partially

transmissive partially reflective lens **108** (i.e., at least one of **108**R and **108**L). Optical elements **132** are configured and operative to convey and project the image produced by light display **130** onto partially transmissive partially reflective lens **108**, as will be described in greater detail below in conjunction with FIGS. **4** and **5**.

FIG. **3**B illustrates an accessorized configuration of electro-optical unit **102** of OST NED system **100**, denoted by $\mathbf{102}_2$, having additional components with respect to the basic configuration of electro-optical unit configuration $\mathbf{102}_1$, shown in FIG. **3**A. Electro-optical unit **102** includes an electronics module $\mathbf{104}_2$, and optical module **106** (i.e., identical to that in FIG. **3**A). According to the accessorized configuration, electronics module $\mathbf{104}_2$ includes light display **130** (i.e., identical to that in FIG. **3**A), and may optionally include at least one of a processor **134**, a memory device **136**, a user interface **138**, and a communication module **140**. Processor **134** is configured and operative to be communicatively coupled (i.e., wired, wirelessly thereby enabling to at least one of send and receive signals and data) to light display **130**, memory device **136**, user interface **138**, and communication module **140** (interconnections not shown in FIG. **3**B). Electro-optical unit $\mathbf{102}_2$ is electrically powered by a power source (not shown). The power source may be embodied in the form of at least one battery that may be housed in user attachment section **112**, such as in stem portions **114**R and **114**L. Alternatively or additionally, solar arrays (not shown) may be integrated with frame **112** and/or with partially transmissive partially reflective lens **108** (e.g., by employing transparent solar arrays, known in the art (e.g., solar window technology)).

With reference to FIG. **4**, frame **112** (FIGS. **1** and **2**) enables detachable mounting of OST NED **100** system to a head **12** of user **10**. Particularly, FIG. **4** shows OST NED system **100** in a mounted configuration on head **12** of user **10** (i.e., being worn). Temples **114**R, **114**L, and nosepiece **116** are constructed and operative to support OST NED system **100**, on the ears **14**R, **14**L and nose **16** (respectively) of user **10** (FIG. **4**). Partially transmissive partially reflective lenses **108**R and **108**L are coupled with frame **112**, and each configured to be facing eyes **18**R and **18**L (respectively) of user **10** wearing OST NED system **100**. Specifically, lens **108**R is configured to be facing a right eye **18**R, and lens **108**L is configured to be facing a left eye **18**L of user **10**. When OST NED system **100** is in a mounted configuration on user **10**, user attachment section **112** is configured to enable electro-optical unit **102** including housing **110** to be positioned within a glabellar region **20** of user's head **12**, as shown in FIG. **4**. Glabellar region **20** is defined herein as an area covering the glabella (also known as the mesophryon), which, in humans, is an anatomical area between the eyebrows and above the nose **16**.

Optical elements (components) **132** (FIGS. **3**A and **3**B) of optical module **106** as shown in FIG. **4** are further described in greater detail in conjunction with FIG. **5** that illustrates a schematic diagram of a light path through optical module **106** of electro-optical unit **102** of OST NED **100**. Electro-optical unit **102** (i.e., $\mathbf{102}_1$ and $\mathbf{102}_2$) includes light display **130**, and optical elements **132** of optical module **106** that include a first lens **140** (FIG. **5**), a reflector **142**, a second lens **146**, a third lens **148**, a fourth lens **150**, a curved mirror **152**, and a partially transmissive partially reflective element **154**. Further shown in FIG. **5** is partially transmissive partially reflective lens **108**, and aperture **156** (herein denoted interchangeably as "light display exit pupil"), and an intermediate image (not shown) that forms at an intermediate image plane **144** between first lens **140** and second lens **146**. In general, each partially transmissive partially reflective lens **108** includes an inner surface **160** (herein interchangeably denoted "user-facing surface"), and an outer surface **162** (herein interchangeably denoted "outward-facing surface"). Inner surface **160** is characterized by an inner surface radius of curvature r_i exhibiting a first optical power P_i. Outer surface **162** is characterized by an outer surface radius of curvature r_o exhibiting a first optical power P_o. In a mounted configuration of OST NED system **100** on user **10**, inner surface **160** is configured to be facing an eye **14**(R,L) of user **10** and outer surface **162** is configured to be facing an outward scene directed away from user **10**. Partially transmissive partially reflective lens **108** is configured to at least partially transmit incoming light of an outward scene, impinging on outer surface **162** and exiting from inner surface **160** toward eye **14**(R,L) of user **10**.

Optical elements **132** of optical module **106**, light display **130** of electronics module **104**, and partially transmissive partially reflective lens **108** form an optical arrangement (herein interchangeably "optical configuration") allowing light rays to propagate as illustrated in FIGS. **4** and **5**. The optical configuration enables light display **130** to project a light beam image (not shown) onto partially transmissive partially reflective lens **108** (i.e., at least one of **108**R and **108**L) along an optical path represented by light rays **158**. Specifically, light display **130** is configured and operative to produce and irradiate the light beam image (i.e., light encoded data defined as light containing data) that propagates along the optical path described as follows. Light display **130** produces the light beam that impinges onto first main reflector **154**, which in turn is configured to reflect the light beam toward third lens **148**, which in turn is configured to refract the light beam and convey it toward fourth lens **150**, which in turn is configured to refract the light beam and convey it toward curved mirror **152**. Curved mirror **152** is configured to reflect the light beam back toward fourth lens **150**, which in turn is configured to refract the light beam again in reverse order and convey it toward third lens **148**. Third lens **148** is configured to refract the light beam and convey it toward second lens **146**, which in turn is configured to refract the light beam and convey it toward auxiliary reflector **142**. Auxiliary reflector **142** is configured to fold the light beam (not shown) and reflect it toward first lens **140**. First lens **140** is configured to refract the light beam and convey it toward partially transmissive partially reflective lens **108**. Partially transmissive partially reflective lens **108** is configured to reflect the light beam toward at least one eye **18**R, **18**L of user **10**.

Inner surface **160** of partially transmissive partially reflective lens **108**, which is characterized by inner surface radius of curvature r_i exhibiting a first optical power P_i, is configured to provide ophthalmic correction with respect to the reflected light beam for viewing by at least one eye of the user. Generally, each partially transmissive partially reflective lens $\mathbf{108}_1$ and $\mathbf{108}_2$ that is associated with a particular eye (i.e., **18**R, **18**L) of user **10** (i.e., associated in the sense of configured to be facing that eye in a mounted configuration of OST NED system **100**), is configured to provide a corresponding ophthalmic correction with respect to its associated eye. The characteristics of each partially transmissive partially reflective lens are tailored to the specific ophthalmic correction required for each associated eye of the user. Accordingly, each partially transmissive partially reflective lens $\mathbf{108}_1$ and $\mathbf{108}_2$ is configured to exhibit its corresponding inner surface radius of curvature $r_{i(1)}$ and $r_{i(2)}$, respectively, and its corresponding first optical power $P_{i(1)}$, $P_{i(2)}$, respectively. Partially transmissive partially reflective

lenses 108_1 and 108_2 may have the same characteristics (i.e., inner surface radius of curvature, and optical power), or alternatively, different characteristics with respect to each other.

The optical path of the light beams (i.e., exemplified as rays **158** in FIG. **5**) originate from light display **130**, reflect off partially transmissive partially reflective element **154**, pass through lenses **148** and **150**, reflect from curved mirror **152**, pass through (i.e., refract by) lenses **150** and **148** again (i.e., and in reverse order), then pass through lenses **146** and **140**, and in due course, reflect from inner surface **160** of partially transmissive partially reflective lens **108** toward an eye (**18**R, **18**L) of user **10**. Intermediate image forms at intermediate image plane **144** along the optical path between first lens **140** and second lens **146**, and particularly between auxiliary reflector **142** and second lens **146**. Specifically, second lens **146** is configured and operative to be positioned along the optical path and have optical characteristics (e.g., optical power) that allows intermediate image to form at intermediate image plane **144** located perpendicularly along the optical path between itself (second lens **146**) and first lens **140**. Auxiliary reflector **142** (e.g., fold mirror) facilitates in the minimization of the spatial dimensions of electro-optical unit **102** so that it may substantially meet the spatial constraints of being located substantially at glabellar region **20** of user **10**.

In accordance with the disclosed technique, OST NED system **100** is configured and operative to generate and to project light encoded data (i.e., light containing data) in the form of a light representation (e.g., an image, graphical information, symbology, etc.) onto partially transmissive partially reflective lens **108**, the latter of which is configured and operative concurrently, to at least partially reflect the light (i.e., which is encoded with data or that contains information) toward the eyes (**18**R, **18**L) of user **10** (FIG. **4**, shown as an example for right eye **18**R) who wears the system, as well as to at least partially transmit incoming light from a scene in the user's field of regard (i.e., outward-facing environment with respect to the user). Partially transmissive partially reflective lens **108** essentially acts as an optically collimated transparent (or translucent) display enabling the overlay of images and other data projected onto its surfaces (i.e., a combiner), without obstructing a scene viewed by the user.

In accordance with the disclosed technique, OST NED system **100** is configured and operative to generate and to project light encoded data (i.e., light containing data) in the form of a light representation (e.g., an image, graphical information). In the basic configuration shown in FIG. **3**A, light display **130** is configured to receive data (e.g., image information from an external source (not shown)) and to generate, irradiate, and project light encoded data in the form of a light representation and to convey the light encoded data toward optical elements **132** of electro-optical unit **102**. Alternatively, light display **130** incorporates an internal memory unit (not shown) configured and operative to store data (e.g., image information), which light display **130** uses to generate the light encoded data.

In the accessorized configuration shown in FIG. **3**B, processor **134** (FIG. **3**B) is configured and operative to produce, process, and modify, data (not shown), for example in the form of electrical signals that convey image data and/or graphical representation data and to provide (communicate) this data to light display **130**. Memory device **136** is configured and operative to store this image data for manipulation (e.g., by processing and modification) and for retrieval (e.g., by processor, by light display **130**). Memory device **136** is generally embodied in the form of non-volatile memory (e.g., read-only memory (ROM), flash memory, magnetic storage devices (e.g., hard disks), ferroelectric read-only memory (F-RAM), optical memory (e.g., optical discs), etc.) as well as volatile memory (e.g., RAM).

Light display **130** is configured and operative to receive data, generate light encoded data based on the data received therefrom, irradiate and project the light encoded data toward partially transmissive partially reflective element **154**. The terms "light encoded data" and "light encoded information" used interchangeably herein, generally refer to light that is encoded with data, and more specifically, to light that contains information that is exhibited in at least one domain, such as in the spectral domain (i.e., wavelengths-colors), in the spatial domain (e.g., in one or multi-dimensions, such as a one-dimensional (1-D) image (e.g., a point, or pixel), a two-dimensional (2-D) image, a three-dimensional (3-D) image), in the temporal domain (e.g., changing-frame rate), in the polarization domain (e.g., by using light polarization encoding techniques), and the like. For example, in case where the encoded data is 2-D color video, the light encoded data that is generated and projected exhibits change in the temporal domain (i.e., as a succession of image frames), in the spatial domain (i.e., as changes in the image space—as in the case of moving objects within the image frames), in the color domain (i.e., representing the different colors of objects in the images), as well in the light intensity domain (i.e., representing, for example the luminance).

Particularly, light display **130** receives data (e.g., externally, from an internal memory device, from processor **134**), and generates a collimated light beam (encoded with data) shown representationally in FIG. **5** as a plurality of light rays emanating from light display **130** toward partially transmissive partially reflective element **154**. Partially transmissive partially reflective element **154** reflects the light beam toward lens **148**, which is typically a convex-concave (meniscus) lens, which in turn refracts this light beam and relays the refracted light beam toward lens **150**, the latter of which is optically aligned with respect to lens **148**. Lens **150** refracts the refracted light beam relayed from lens **148** and directs the beam toward curved mirror **152**, the latter of which is optically aligned with the former. Lens **150** is typically a concave-convex (meniscus) lens, and curved mirror **152** is typically a concave spherical (front surface or alternatively, a rear surface) mirror. Alternatively, mirror **152** may exhibit curvatures other than spherical, such as aspherical, hyberbolic, elliptical, parabolic, toroidal, and the like. The optical elements group (combination) which includes lens **148**, lens **150**, and curved mirror **152** is constructed and optically arranged to correct aberrations such as astigmatism and distortion that is caused by the optical characteristics such as the curvature of partially transmissive partially reflective lens **108**. The refracted light beam arriving from lens **150** impinges curved mirror **152** such that the consequent reflected light beam is directed to pass (again) through lenses **150** and **148**, thereby forming an angle with respect to the incoming refracted light beam. The combination of curved mirror **152** and lenses **148** and **150** allow the incoming light beam generated and irradiated from light display **130** to pass (refract) twice through lenses **148** and **150**, thereby enabling pre-emptive correction of astigmatism and distortion caused when the light beam reflects off partially transmissive partially reflective lens **108**. Generally, in oblique astigmatism, off-axis rays of light from radial and tangential lines in an object plane focus at different distances in the image space. The utilization of lens

148 with lens 150 in the optical arrangement functions to increase the optical power of the optical system by decreasing the overall focal length of optical elements and in effect, enabling a reduction of the physical dimensions of electro-optical unit 102, as well as further enabling fine-tuning for minimizing astigmatism and distortion.

Second lens 146 receives the refracted light beam from third and fourth lenses 148 and 150, refracts and relays the light beam toward first lens 140 in optical module 106. Third and fourth lenses 148 and 150 are typically of biconvex type (although other types may be used, e.g., plano-convex). As mentioned, second lens 146 is optically configured and operative to form intermediate image (not shown) at intermediate image plane 144 located at a position along an optical path between first lens 140 and second lens 146. Further located at a position along this optical path between first and second lenses 140 and 146 is positioned auxiliary reflector 142 (e.g., a planar folding mirror), which is optically configured and operative to reflect light beams from second lens 146 toward first lens 140, and is employed to bend the optical path into a particular spatial configuration (e.g., required at least for minimizing the spatial dimensions of housing 110 (FIG. 2) of electro-optical unit 102). Minimization of spatial dimensions that is at least partially enabled by bending the light beams of the optical path facilitate in meeting the spatial constraints of housing 110 being located substantially at glabellar region 20 of user 10. The formation of an intermediate image facilitates in the magnification of on outputted generated image, as well as in the widening of the field of view (FOV) that is presented to the user. The formed intermediate image is an aberration-compensated image (or aberration-corrected image) owing to the optical arrangement (and optical characteristics) of curved mirror 152 and lenses 148 and 150. This aberration-compensated formed intermediate image forestalls aberrations produced, at least partially, by the curvature of partially transmissive partially reflective lens 108, such that light rays incident upon and reflecting therefrom are aberration-corrected.

Partially transmissive partially reflective lens 108 is constructed and operative to partially reflect the light beam impinging thereon from light display 130 (i.e., an image source), and partially transmit incoming light from an outward translucent view in the ambient environment (i.e., a scene). Partially transmissive partially reflective lens 108 effectively functions as a light combiner, such that light from the image source and light from the outward scene are combined to form a combined image (not shown) that is directed and provided to at least one eye of the user. Additionally, partially transmissive partially reflective lens 108 is an ophthalmic lens configured and operative to provide ophthalmic (vision) correction to user 10. Essentially, each partially transmissive partially reflective lens 108R and 108L is a corrective lens used to improve vision of the user (e.g., by correcting for refractive errors of the user's eye(s) 18R, 18L (respectively) such as myopia, hyperopia, presbyopia, and the like). Furthermore, both partially transmissive partially reflective lenses 108L and 108R for both the user's left and right eyes 18L and 18R (respectively) are adapted to match the interpupillary distance (IPD) of that user. As such, partially transmissive partially reflective lens 108 is typically constructed from rigid, durable, lens-grade materials such as glass (e.g., optical crown glass), polycarbonate, and the like, as well as at least one reflective optical coating layer whose thickness (at least to some degree) determines its reflective characteristics. The ratio of reflection to transmission, which is typically dependent on the wavelength of light incident on partially transmissive partially reflective lens 108, may vary. Characteristic reflection percentages typically range between 20-40%; whereas total transmission percentages typically range between 8-70%. Any ratio derived from these percentages is viable. In particular, there may be more than one reflection to transmission ratios of partially transmissive partially reflective lens 108 (which may be different or the same). One reflection to transmission ratio is associated with light impinging on inner surface 160 (produced by light display 130), the other associated with light impinging on outer surface 162. According to one realization, the reflectivity of outer surface 162 may be greater than the reflectivity of inner surface 160. Other, different realizations may be possible, for example, where outer surface 162 (i.e., and/or at least part of partially transmissive partially reflective lens 108) may be embedded with silver halide (silver salts) in microcrystalline form that endow photochromic properties to the lens. The following features and options may apply differently or equally to each partially transmissive partially reflective lens 108R and 108L. Optionally, an antireflection coating may also be applied to outer surface 162. Further optionally, an anti-abrasion coating may also be applied to partially transmissive partially reflective lens 108. Further optionally, an anti-fog coating may be applied to partially transmissive partially reflective lens 108. Further optionally, partially transmissive partially reflective lens 108 may be coated and/or incorporate light-polarized material, which generally enhances the contrast of an image viewed through the lens (e.g., especially noticeable in snow covered environments). Partially transmissive partially reflective lens 108 may employ shatter resistant ("shatterproof") materials (e.g., polyvinyl butyral (PVB), ethylene-vinyl acetate (EVA), thermoplastic polyurethane (TPU), polyethylene terephthalate (PET), polycarbonate (PC), combinations thereof, etc.) in its construction and/or manufacture such that it exhibits shatterproof and impact-resistant qualities. Moreover, partially transmissive partially reflective lens 108 complies with known safety standards of eyewear in general, and eyewear (e.g., sunglasses) used for sporting applications, in particular.

Partially transmissive partially reflective lens 108 reflects the light beam from first lens 140, passing through light display pupil 156 and toward the eye of the user, where dotted-line 164 represents a position of a plane that indicates the front eye surface of eye (18R, 18L) of user. Dotted-line 164 is disposed along the optical path between partially transmissive partially reflective lens 108 and light display pupil 156. As will be described in greater detail hereinbelow, OST NED system 100 incorporates a non-pupil forming optical design thereby enabling a favorable visual experience for viewing the light image emitted by light display 130 across a wide FOV.

According to another embodiment of the disclosed technique, OST NED system 100 is configured and operative with an eye-tracking system. As such there is thus provided an optical configuration for an OST eye-tracking system that includes partially transmissive partially reflective lens (combiner) and an electro-optical unit that includes an image sensor, configured to acquire at least one image of an eyeball feature of an eye of the user, with reflected light from the eye. To further elucidate the particulars of this embodiment of the disclosed technique, reference is now made to FIGS. 6A, 6B, and 7. FIG. 6A is a schematic block diagram of a basic configuration of an electro-optical unit of OST eye-tracking system, constructed and operative in accordance with another embodiment of the disclosed technique. FIG.

6B is a schematic block diagram of an accessorized configuration of an electro-optical unit of OST eye-tracking system, constructed and operative in accordance with the embodiment of the disclosed technique. FIG. **7** is a schematic diagram of a light path through an optical module of electro-optical unit of OST eye-tracking system, constructed and operative in accordance with the embodiment of the disclosed technique.

OST eye-tracking system **200** (not number-referenced in Figures) (herein denoted interchangeably as "OST NED eye-tracking system") generally incorporates similar features and components of OST NED system **100**, however, OST NED eye-tracking system **200** includes an electro-optical unit that employs an eye-tracker as detailed below. FIG. **6**A illustrates a basic configuration of an electro-optical unit of OST NED eye-tracking system **200**, denoted by $\mathbf{202}_1$. Electro-optical unit $\mathbf{202}_1$ includes an electronics module $\mathbf{204}_1$, and an optical module **206**. Particularly, electronics module $\mathbf{204}_1$ includes a light display **130**, and eye-tracker **230**. Note that identically referenced numbers in the embodiments OST NED system **100** and OST NED eye-tracking system **200** relate to the same components (i.e., same type and function). (For example, light display **130** in OST NED system **100** shown in FIG. **3**A is identical to light display **130** in OST NED eye-tracking system **200**, shown in FIG. **6**A.) Optical module **206** includes optical elements, collectively referenced **232** that are particularized in greater detail in FIG. **7**. Light display **130** of electronics module $\mathbf{204}_1$ along with optical elements **232** of optical module **206** form a light projector that is configured and operative to produce, irradiate, and project a light beam image (not shown) onto at least one partially transmissive partially reflective lens **108** (i.e., at least one of **108**R and **108**L), in a similar manner described hereinabove with respect to OST NED system **100**. Optical elements **232** are configured and operative to convey and project the image produced by light display **130** onto partially transmissive partially reflective lens **108**.

FIG. **6**B illustrates an accessorized configuration of electro-optical unit **102** of OST NED eye-tracking system **200**, denoted by $\mathbf{202}_2$, having additional components with respect to the basic configuration of electro-optical unit configuration $\mathbf{202}_1$, shown in FIG. **6**A. Electro-optical unit $\mathbf{202}_2$ includes an electronics module $\mathbf{204}_2$ and optical module **206** (i.e., identical to that in FIG. **6**A). According to the accessorized configuration, electronics module $\mathbf{204}_2$ includes light display **130**, an eye-tracker **230** (i.e., identical to that in FIG. **6**A), and may optionally include at least one of a processor **134**, a memory device **136**, a user interface **138**, and a communication module **140**. Processor **134**, memory device **136**, user interface **138**, and communication module **140** are identical to those shown in FIG. **3**B, except for added configuration, functionality, and features (e.g., software) associated with eye-tracker **230**. Optical elements (components) **232** (FIGS. **6**A and **6**B) of optical module **206** are further described in greater detail in conjunction with FIG. **7**.

With particular reference now to FIG. **7**, which is an illustration showing a schematic diagram of two light paths through optical module **206** of electro-optical units $\mathbf{202}_1$ and $\mathbf{202}_2$ of OST NED eye-tracking system **200**. Eye tracker **230** typically includes several components of an image sensor $\mathbf{230}_1$ and two lenses $\mathbf{230}_2$, $\mathbf{230}_3$, as shown in FIG. **7**. Image sensor $\mathbf{230}_1$ is part of electronics module $\mathbf{204}_1$ of electro-optical units $\mathbf{202}_1$ and $\mathbf{202}_2$, and lenses $\mathbf{230}_2$ and $\mathbf{230}_3$ are part of optical elements **232** of optical module **206** of electro-optical units $\mathbf{202}_1$ and $\mathbf{202}_2$ (with reference to FIGS. **6**A and **6**B). For both basic and accessorized configurations, eye-tracker **230** may further optionally include at least one light source (e.g., visible and/or infrared light emitter(s)—not shown) that is configured and operative to illuminate at least one eye of the user, thereby facilitating in tracking the eye position (e.g., gazing direction, from eyeball features such as the pupil, as known in the art). All other components shown in FIG. **7** having the same reference numbers as those shown in FIG. **5** are identical to each other. In that respect OST NED eye-tracking system **200** is similar to OST NED system **100**. FIG. **7** illustrates two light ray bundles (beams) **158** and **168** propagating along two different light paths. Light rays **158** represent an optical path of light display **130**, while light rays **168** represent an optical path associated with eye-tracker **230**.

Specifically, electro-optical unit **202** (i.e., $\mathbf{202}_1$ and $\mathbf{202}_2$) includes light display **130**, and optical elements **232** of optical module **206** that include first lens **140**, reflector **142**, second lens **146**, third lens **148**, fourth lens **150**, curved mirror **152**, partially transmissive partially reflective element **154**, and lenses $\mathbf{230}_2$ and $\mathbf{230}_3$ of eye-tracker **230**. FIG. **7** further shows partially transmissive partially reflective lens **108**, aperture **156** (herein denoted interchangeably as "light display exit pupil"), an intermediate image plane **144** where an intermediate image of light display (not shown) forms between first lens **140** and second lens **146**, as well an intermediate image plane **166** where an intermediate image of eye-tracker (not shown) forms at between third lens **148** and second lens **146**. Partially transmissive partially reflective lens **108** is the same as described in conjunction with FIG. **5** (i.e., it includes inner surface **160** and outer surface **162**, whereby inner surface **160** is characterized by an inner surface radius of curvature r_i exhibiting a first optical power P_i and outer surface **162** is characterized by an outer surface radius of curvature r_o exhibiting a first optical power P_o).

Optical elements **232** of optical module **206**, light display **130** of electronics modules $\mathbf{204}_1$ and $\mathbf{204}_2$, and partially transmissive partially reflective lens **108** form an optical arrangement (herein interchangeably "optical configuration") allowing light rays to propagate along two light beams **158** and **168**, as illustrated in FIG. **7**. Reflected light from the eye (i.e., front eye surface (dotted-line **164**) of the user (i.e., natural (ambient) light, or artificial light (from a dedicated light source), or both) reflects off the eyeball of the user and that light is made to traverse an optical path that travels such that at least partially reflects from partially transmissive partially reflective lens **108**; then refracts through first lens **140**, second lens **146**, third lens **148**, and fourth lens **150**, then reflects from curved mirror **152** and refracts again in reverse order through fourth lens **150** and then through third lens **148**, then at least partially passing through partially transmissive partially reflective element (optical combiner) **154**, refracts through lenses $\mathbf{230}_2$ and $\mathbf{230}_3$, and impinges on image sensor $\mathbf{230}_1$. Image sensor $\mathbf{230}_1$ is configured and operative to acquire an image (not shown) of the eyeball (i.e., having at least one eyeball feature such as the pupil), to produce image data corresponding the acquired image, and to enable the communication of the image data to processor **134** for processing.

The optical configuration enables light display **130** to project a light beam image (not shown) onto partially transmissive partially reflective lens **108** (i.e., at least one of **108**R and **108**L) along the optical path represented by light rays **158** (as described in hereinabove in conjunction with FIG. **5**) simultaneously while eye-tracker **230** tracks the eye of the user along the optical path represented by light rays **168**. Partially transmissive partially reflective element **154**

(combiner) functions both as a fold mirror as well as a cold mirror that is configured and operative to reflect at least one range of wavelengths of light in electro-magnetic (EM) spectrum (i.e., typically visible light from produced by light display **130**), while transmitting at least another range of wavelengths of light in the EM spectrum (i.e., typically infrared (IR) light captured by image sensor $\mathbf{230}_1$). Combiner **154** exhibits optical characteristics that include being 90% transmissive at a wavelength of 850 nm (nanometers), as well as being 90% reflective between the wavelength range of 450-650 nm. Optional flood lights (e.g., IR light-emitting diodes (LEDs)) may be used to illuminate the eye of the user thus enabling image sensor $\mathbf{230}_1$ to detect IR light reflecting off the eye. When illuminating the eye of user with IR light the user's pupil appears as a "dark pupil" facilitates detection and determination of eye pupil position (e.g., gaze direction) of the user. Image sensor $\mathbf{230}_1$ may be optimized to detect IR light at 850 nm, and may typically be based on a complementary metal-oxide-semiconductor (CMOS) technology, charge-coupled device (CCD) technology, and the like. Additional characteristics of image sensor $\mathbf{230}_1$ include it being of small size on the order of a few millimeters, incorporating a global shutter, and a sampling rate of 120 Hz, and a typical FOV of 50 degrees. Lenses $\mathbf{230}_2$ and $\mathbf{230}_3$ are typically embodied as aspheric lenses and configured and operative to focus light from eye front surface (represented by dotted line **164**) to image sensor $\mathbf{230}_1$.

OST NED eye-tracking system **200** enables an eye coverage area of approximately, 20×20 mm, and gaze coverage of ±35 degrees (left and right), an eye box of 7×3 mm that is adapted to different IPDs. OST NED eye-tracking system **200**, and particularly processor **134**, based on image data acquired from image sensor $\mathbf{230}_1$, are configured and operative to detect blinking of the eye of the user, as well as for gaze orientation tracking, user-interface interaction, IPD adjustment, line-of-sight (LOS) stabilization, focus distance estimation, near field AR auto-correction for parallax (i.e., eye-camera-LOS), as well as fatigue detection.

Reference is now made to FIGS. **8**A, **8**B, and **8**C. FIG. **8**A is a schematic illustration showing the principles of the non-pupil forming optical design upon which OST NED system **100** and OST NED eye-tracking system **200** are based, in accordance with the embodiments of the disclosed technique. FIG. **8**B is a schematic illustration showing the a simplified geometric representation of a human eye, looking at a projected image focused at a far distance, and generated by a non-forming exit pupil display system design upon which OST NED system **100** and OST NED eye-tracking system **200** are based, in accordance with the embodiments of the disclosed technique. FIG. **8**C is a schematic illustration showing determination of the distance, d, of the system exit pupil to the eye pupil, according to the disclosed technique.

FIG. **8**A shows a simplified geometric representation of a human eye (**18**R, **18**L, also denoted interchangeably herein "**18** (R,L)", and simply "**18**") that is gazing at a projected image (not shown) focused at a far distance therefrom, and generated by a non-pupil forming exit display system, in accordance with the principles of the disclosed technique. As eye **18**R,L of user looks to one side of the FOV at an angle (±) a (degrees), a portion of a ray bundle penetrates the eye's pupil **24**. At the center of the FOV near an eye projection system, the user will be expected to see the whole image of the display (e.g. the center of the field using central vision, as well as the sides of the field using peripheral vision). Further, while looking to the sides of the FOV of a near-eye projection system, the user is expected to clearly see the side of the field using central vision, and the remaining field using peripheral vision. From FIG. **8**A it is clear that achieving that expectation for visual experience requires consideration and specific design to optimize the configuration of the eye projection system, such that the design position of the exit pupil of the eye projection system is taken into account with respect to the eye pupil position, as well as with respect to the size of the pupil, the size of the bundle of rays arriving from the projection unit (from each direction across the field of view), as well as the total size of the field of view of the projection unit.

Referring now to FIG. **8**B, FIG. **8**B is a schematic illustration showing a simplified geometric representation of human eye **18**R, **18**L, looking at a projected image (not shown) that is focused at a far distance from a user. A user of the OST NED system **100** and OST NED eye-tracking system **200** gazes at the projected image focused at a far distance, and that is generated by a non-pupil forming exit display system, in accordance with the embodiments of the disclosed technique. FIG. **8**B shows a representation of three bundles of light rays arriving at angles 0, and ±α, which are to be considered as arriving from the projection display system, which is interchangeably denotes light display **130**. The light ray bundle represents portions of the FOV of the display (e.g. the bundle of light rays arriving at an angle of zero degrees originate at the center of the FOV of light display **130**). Similarly, assuming a represents the maximal angle of view of the projection display system, the bundle of light rays arriving at angle of +α degrees originate at one side of light display **130**. Furthermore, FIG. **8**B includes annotations, were R represents the eye's **18** (R, L) radius of rotation, r represents the distance of eye's pupil **24** from eye's **18** (R, L) center of rotation, d represents the distance of eye's pupil **24** to the eye projection system exit pupil, and x represents a diameter of the bundle of light rays. When the user's eye looks straight ahead at an angle of 0 degrees, a portion of the light ray bundle penetrates pupil **24**. In addition, at least a portion of the light ray bundles arriving from the range of angles +α to 0° and −α to 0° also penetrate pupil **24**. This situation represents a case were eye **18** (R, L) is able to see both the center of the FOV of light display **130** (known as "central vision", imaged by the eye's fovea), as well as the sides of the FOV of the light display **130** (known as "peripheral vision").

Referring now to FIG. **8**C, which shows a schematic illustration for facilitating the determination of the distance, d, of the system exit pupil to the eye pupil, according to the disclosed technique, where x represents a (projected) light ray bundle diameter ("light ray bundle fan size"), r represents the distance of the eye's pupil from the eye's center of rotation, p represents the pupil diameter, A represents the projected distance between the center of the pupil and the center of the optical exit pupil. The schematic illustrates two poses (positions and orientations) of the eye: (1) looking forward, and (2) looking to the side at an angle of a, which is half the FOV as shown in FIGS. **8**A-C (i.e., at the direction of light rays arriving from light display **130**). From FIG. **8**C it is determined that the optimal position for the exit pupil of the eye projection system is according to the following formula:

$$d > r - \left(\frac{x+p}{2\sin\alpha}\right), \tag{1}$$

where d represents the distance between the exit pupil to a position located behind the eye's pupil (i.e., inside the eye).

At positions d satisfying formula (1), the whole aperture is configured to be covered or illuminated with light rays. Similarly, from FIG. **8**C it is determined that while the user gazes forward, the optimal position for the exit pupil of the eye projection system (light display **130**) is dictated according to the following formula:

$$d < \frac{x + p(\cos \propto)}{2\sin \propto}, \quad (2)$$

where d represents the distance between the exit pupil to a position located in-front of the pupil (i.e., facing forward the eye). OST NED system **100** and OST NED eye-tracking system **200** with a non-pupil forming exit abiding according to equations (1) and (2) enable an optimal visual experience for viewing light display **130** across its entire FOV.

In accordance with the disclosed technique, OST NED system **100** and OST NED eye-tracking system **200** are characterized by several important features which will be described hereinbelow in greater detail. Reference is now made to FIG. **9**A, which is a schematic illustration showing optical design features of the systems of the disclosed technique with respect to an eye motion box in relation to an exit aperture. The center portion of FIG. **9**A illustrates a simplified schematic illustration showing user **10**, partially transmissive partially reflective lens **108** (interchangeably "visor", and "combiner"), an exit aperture **240**, and a system pupil **242**. The top right portion of FIG. **9**A illustrates a coordinate system whose origin is located at the user's eye pupil position. An eye motion box is determined by exit aperture **240** (and eye position). The position and orientation (P&O) of light display **130** is determined by the combiner (visor) rake angle. The image angle with respect to the real-world outward scene horizon is dictated by the angle of attack and the P&O of light display **130**. The position of the eye and the eye box in conjunction with the conferred FOV to the user is dependent upon the "visor distance" (i.e., the distance between system pupil **242** and partially transmissive partially reflective lens **108**), which in turn is determines the size of exit aperture **240**. FIG. **9**A further shows the visor rake angle (also referred as the "pantoscopic angle").

To further explain the pantoscopic angle's relation to the disclosed technique, reference is now further made to FIG. **9**B, which is a schematic illustration showing a pantoscopic angle, a wrap angle, and a roll angle, according to the principles of the disclosed technique. The pantoscopic angle is defined as an angle between a plane of partially transmissive partially reflective lens (combiner) **108** and the vertical y-axis, as indicated in FIG. **9**A. Mathematically, the pantoscopic angle is defined as: cos(Roll)*Tilt. FIG. **9**B shows a side partial view of user **10**, and combiner **108**, where the vertical dotted line indicates the vertical axis (y-axis), and a pantoscopic angle from a plane of combiner **108** to the vertical axis. FIG. **9**B further shows a wrap angle (also denoted as total wrap angle of frame **112**), which is a measure of how frame **112** wraps around user's **10** face, and defined mathematically as sin(Roll)*Tilt. The roll angle as shown in FIG. **9**B is defined as the projected exit aperture angle, as illustrated.

The characteristics described hereinabove in conjunction with FIGS. **8**A, **8**B, **9**A and **9**B enable to characterize the OST NED system (and product) according to the disclosed technique exhibiting the following features, characteristics, optical design data, and tolerances:

- OST NED system **100** and OST NED eye-tracking system **200** embodied as a product (apparatus) having the form of eyewear (e.g., eye glasses with ophthalmic correction) is based on free-space optical design having a partially transmissive partially reflective lens **108** (i.e., combiner, visor), and an electro-optical unit (that includes light display **130**);
- Partially transmissive partially reflective lens **108** (combiner, visor) exhibits a pantoscopic tilt of 22 degrees (herein abbreviated "deg." or °)±4 deg., and a wrap angle of 22 deg. ±4 deg. and curvature radii of 100 mm±34 mm;
- Partially transmissive partially reflective lens **108** maximal distance from the eye cornea location is 15 mm±2 mm;
- Light display **130** (i.e., image projection unit) has an exit aperture exhibiting a projection angle of 45 deg.±5 deg. roll angle around the Z-axis, and 31 deg.±4 deg. tilt relative to the normal of the visor, and a distance of 6 mm±2 mm from the visor;
- Light display **130** (i.e., image projection unit) exit aperture is positioned relative to the eye pupil location at a minimal distance defined with a borderline at roll angle of 45 deg.±5 deg. around Z axis positioned 14 mm±3 mm from the eye pupil center along Z axis, and a projected distance of at least 8 mm±2 mm from the eye pupil center;
- Light display **130** (i.e., image projection unit) exit aperture has a field of projection 24×13±2 deg. that creates an eye box of 6×3±1 mm; and
- The center of the virtual image is placed at an elevation angle of 2 degrees max.±3 deg. relative to the horizon.

Reference is now made to FIGS. **10**A and **10**B. FIG. **10**A is a schematic illustration showing a front-facing detailed partial view of characteristic design constraints of the systems of the disclosed technique. FIG. **10**B is a schematic illustration showing a detailed side partial view of characteristic design constraints of the systems of the disclosed technique. As shown in FIG. **10**A a dotted line denoted "borderline" represents a borderline of first lens **140** (FIGS. **5** and **7**) with respect to eye **18**R of user **10**. The projected distance from the borderline to the pupil of eye **18**R is 8±2 mm. As shown in FIG. **10**B a dotted line denoted "borderline" represents a borderline of several optical elements **132** (FIG. **5**) and **232** (FIG. **7**) with respect to a distance to pupil of the eye along the Z-axis (FIG. **9**A).

It will be appreciated by persons skilled in the art that the disclosed technique is not limited to what has been particularly shown and described hereinabove. Rather the scope of the disclosed technique is defined only by the claims, which follow.

The invention claimed is:

1. An optical see-through (OST) near-eye display (NED) system, integrating ophthalmic correction for an eye of a user, comprising:

a partially transmissive partially reflective lens, including an inner surface having an inner surface radius of curvature exhibiting a first optical power, and an outer surface having an outer surface radius of curvature exhibiting a second optical power, said partially transmissive partially reflective lens is configured to be facing said eye, and to at least partially transmit incoming light of an outward scene to said eye; and

an electro-optical unit, configured to be optically coupled with said partially transmissive partially reflective lens, said electro-optical unit including a light display, a cold mirror and optical elements, said light display being

configured to project a light beam image onto said cold mirror via said optical elements onto said inner surface, so to enable reflection of said light beam image toward said eye, said electro-optical unit is configured to be located at a glabellar region of said user,

wherein said first optical power is configured to provide ophthalmic correction with respect to reflected said light beam image for viewing by said eye, wherein said second optical power is configured to provide ophthalmic correction with respect to transmitted said incoming light from said outward scene for viewing by said eye.

2. The OST NED system according to claim **1**, wherein said electro-optical unit further includes a processor.

3. The OST NED system according to claim **1**, wherein said optical elements of said electro-optical unit include a first lens, a reflector, a second lens, a third lens, a fourth lens, and a curved mirror.

4. The OST NED system according to claim **3**, wherein said second lens is configured to produce an intermediate image at an intermediate image plane located at a position along an optical path between said second lens and said first lens.

5. The OST NED system according to claim **4**, further including an auxiliary reflector configured to fold said light beam image, said auxiliary reflector is positioned along said optical path between said second lens and said first lens, after said position of said intermediate image plane.

6. The OST NED system according to claim **4**, wherein an optical arrangement of said curved mirror, said third lens, and said fourth lens enables said intermediate image to be aberration-compensated.

7. The OST NED system according to claim **6**, wherein said aberration-compensated said intermediate image is configured to forestall the effect of aberrations produced at least partially by said inner surface radius of curvature of said partially transmissive partially reflective lens.

8. The OST NED system according to claim **7**, wherein said optical aberrations include at least one of astigmatism and distortion.

9. The OST NED system according to claim **3**, wherein said light beam image propagates along an optical path from said light display toward said reflector then toward said third lens, then toward said fourth lens, then toward said curved mirror, then again toward said fourth lens, then again toward said third lens, then toward said second lens, then toward said first lens, then toward said partially transmissive partially reflective lens.

10. The OST NED system according to claim **3**, wherein an optical arrangement of said curved mirror, said third lens, and said fourth lens is configured to correct for optical aberrations caused by the curved surface of said partially transmissive partially reflective lens.

11. The OST NED system according to claim **3**, wherein a combination of said fourth lens and said third lens is configured to increase an optical power of said OST NED system.

12. The OST NED system according to claim **1**, further including a memory device configured for storing image data corresponding to said light beam image.

13. The OST NED system according to claim **1**, wherein said light display is configured to receive data and to generate said light beam image based on said received data.

14. The OST NED system according to claim **1**, wherein a position of an exit pupil for said user is according to:

$$d > r - \left(\frac{x + p}{2\sin\alpha}\right)$$

where d is a distance of said exit pupil from a pupil of said eye of said user, r is a distance of said pupil from said eye center of rotation, p is a pupil diameter, x is a projected ray bundle diameter from said light display, and α is half of a field of view (FOV) of said light display given a gaze direction of said user is equal to α.

15. The OST NED system according to claim **14**, wherein a position for an exit pupil of said image display is according to:

$$d < \frac{x + p(\cos\alpha)}{2\sin\alpha}$$

given a gaze direction of said user is directed to an optical axis of said light display.

16. An optical configuration for an optical see-through (OST) eye-tracking system, comprising:

a partially transmissive partially reflective lens, configured to be facing an eye of a user;

an electro-optical sub-system, comprising:

an image sensor, configured to acquire at least one image of an eyeball feature of said eye with reflected light from said eye;

a first lens;

a second lens;

a third lens;

a fourth lens;

a curved mirror;

an optical combiner;

a cold mirror; and

a fifth lens,

wherein said optical configuration enables said reflected light to travel along an optical path at least partially reflecting from said partially transmissive partially reflective lens; then refracting through said first lens, said second lens, said third lens, and said fourth lens, then reflecting from said curved mirror and refracting again in reverse order through said fourth lens and then through said third lens, then at least partially passing through said cold mirror, refracting through said fifth lens, and impinging on said image sensor.

17. An optical see-through (OST) near-eye display (NED) system, integrating ophthalmic correction for an eye of a user, comprising:

a partially transmissive partially reflective lens, including an inner surface having an inner surface radius of curvature exhibiting a first optical power, and an outer surface having an outer surface radius of curvature exhibiting a second optical power, said partially transmissive partially reflective lens is configured to be facing said eye, and to at least partially transmit incoming light of an outward scene to said eye; and

an electro-optical unit, configured to be optically coupled with said partially transmissive partially reflective lens, said electro-optical unit including a light display configured to project a light beam image onto said onto said inner surface, so to enable reflection of said light

beam image toward said eye, said electro-optical unit is configured to be located at a glabellar region of said user;

wherein said first optical power is configured to provide ophthalmic correction with respect to reflected said light beam image for viewing by said eye, wherein said second optical power is configured to provide ophthalmic correction with respect to transmitted said incoming light from said outward scene for viewing by said eye,

wherein a position of an exit pupil for said user is according to:

$$\frac{x + p(\cos\alpha)}{2\sin\alpha} > d > r - \left(\frac{x + p}{2\sin\alpha}\right)$$

where d is a distance of said exit pupil from a pupil of said eye of said user, r is a distance of said pupil from said eye center of rotation, p is a pupil diameter, x is a projected ray bundle diameter from said light display, and α is half of a field of view (FOV) of said light display given a gaze direction of said user is equal to α.

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